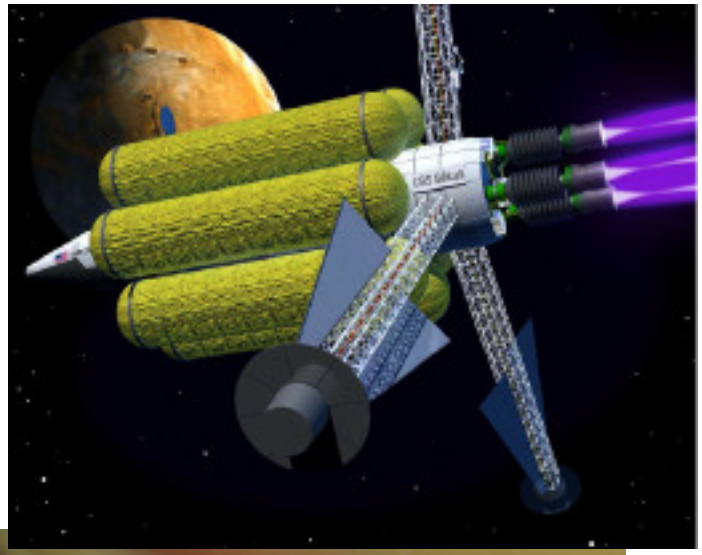
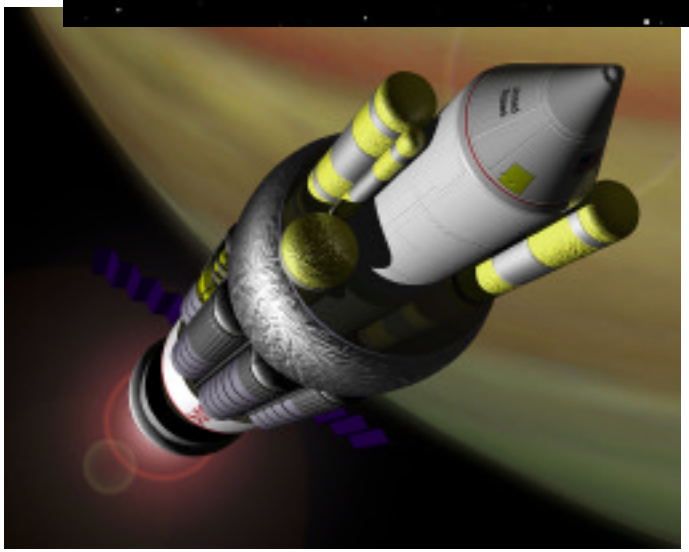
Nuclear Propulsion Concepts

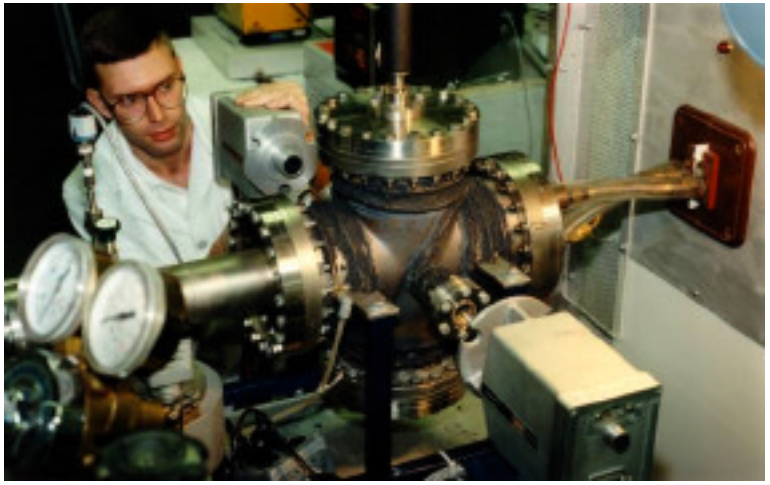
- **Nuclear Thermal and Nuclear Electric**
  - **Nuclear Thermal Rockets (NTR)** typically flow hydrogen gas through the reactor core to heat the gas which provides thrust by expanding through a nozzle. This system provides high thrust with Isp > 800 s.
  - **Nuclear Electric Propulsion (NEP)** typically uses a nuclear reactor to generate electric power (similar to a submarine) which is used to power an electric propulsion system. Low thrust with Isp >> 5000 s.
- **Why sould we consider Nuclear Propulsion????**
  - Chemical propulsion systems have been pushed to limit. Maybe another few % left.
  - Nuclear could put us on a new growth path with a factor of 1,000,000 improvement in specific energy, a factor of 10 to 100 in ISP.
  - In the event the nation decides to pursue this, to be at least a little prepared, a small amount of research now is appropriate.
- **Some Nuclear Concerns**
  - Safety - If we cannot make it “Air Line Safe” we will not propose to build it
  - Testing nuclear systems has been too expensive. Low cost testing is needed.
  - Nuclear weapons technology proliferation -
    - Can we separate propulsion research and weapons?
    - Some old nuclear propulsion concepts definitely cross the line!!



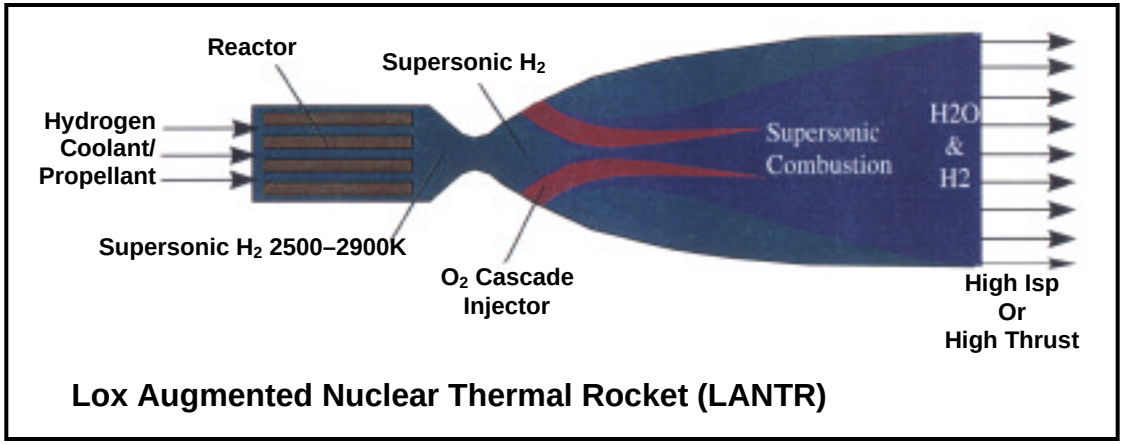


Advanced Nuclear Propulsion Concepts

- **High Temperature Nuclear Fuels**
  - Solid core nuclear reactor performance is limited by the melting point of the nuclear fuel
  - Exotic alloys, sometimes called ribbon fuels, developed by Russia and further developed by the University of Florida, may allow Isp increase from 800 sec. to greater than 1000 sec.
- **LOX Augmented NTR**
  - To assist in escaping the earth's gravitation well liquid oxygen can be injected into the NTR nozzle to increase thrust at the expense of Isp.
  - When the gasses in the nozzle expand and the temperature falls below the molecular dissociation level the oxygen will chemically react with the hydrogen to maintain pressure a little longer.



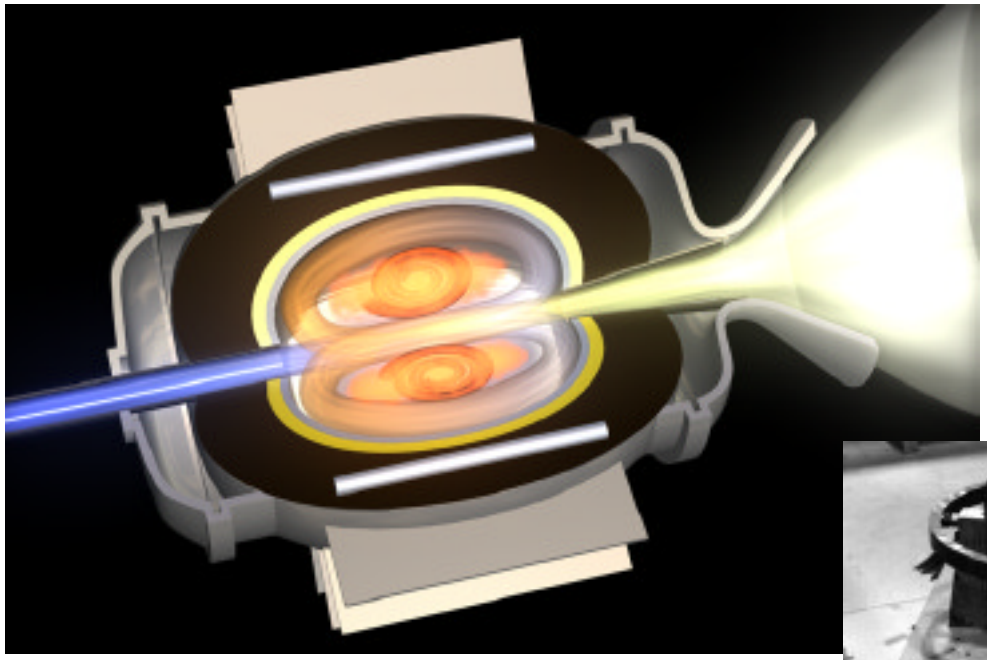
Processing of a Nuclear Fuel Sample



Lox Augmented Nuclear Thermal Rocket (LANTR)

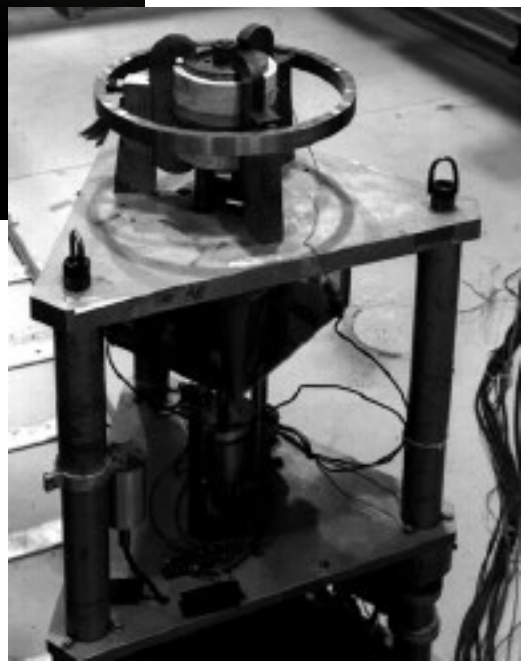
(U,Zr,Nb)C Sample During Sintering

Advanced Nuclear Propulsion Concepts Cont'd

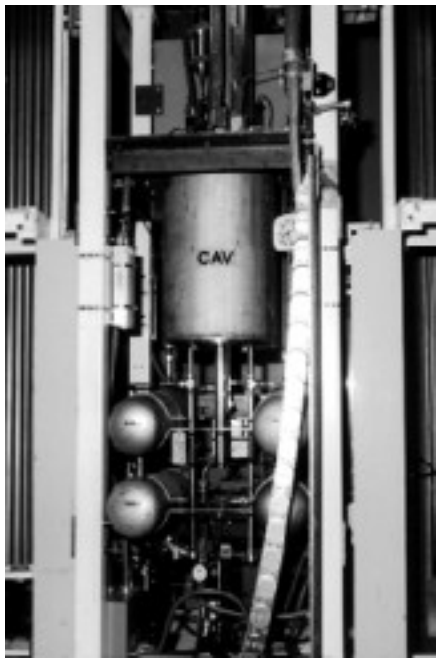


- **Gas Core NTR**
  - Hydrogen gas heated to these very high temperatures may provide Isp > 3000 sec.
  - Los Alamos and Brooklyn Polytechnic Institute have mathematically simulated confinement flow patterns that retain the uranium fuel while releasing the high pressure hydrogen through the nozzle.

- **Pulsed Nuclear Reactors**
  - Reactors that operate in a pulsed mode have been developed by Los Alamos and Sandia for studying the effects of of nuclear weapons bursts.
  - The very high temperatures of the pulse could, in principle, provide very high Isp , but the low pulse repetition frequency may limit its use for propulsion



Godiva

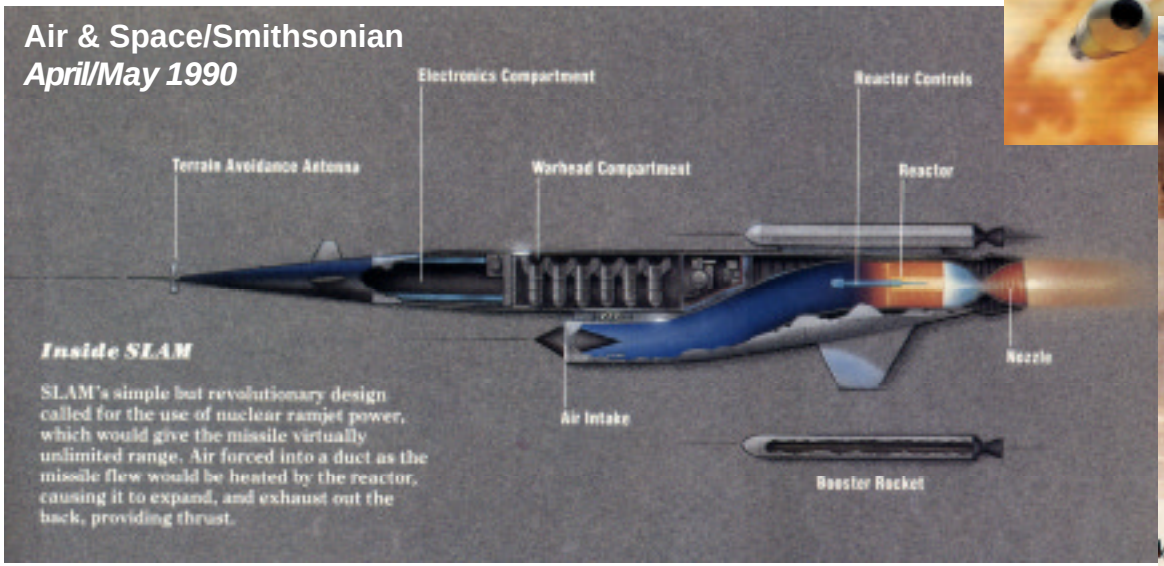


Sheba

Los Alamos Pulsed Nuclear Reactors

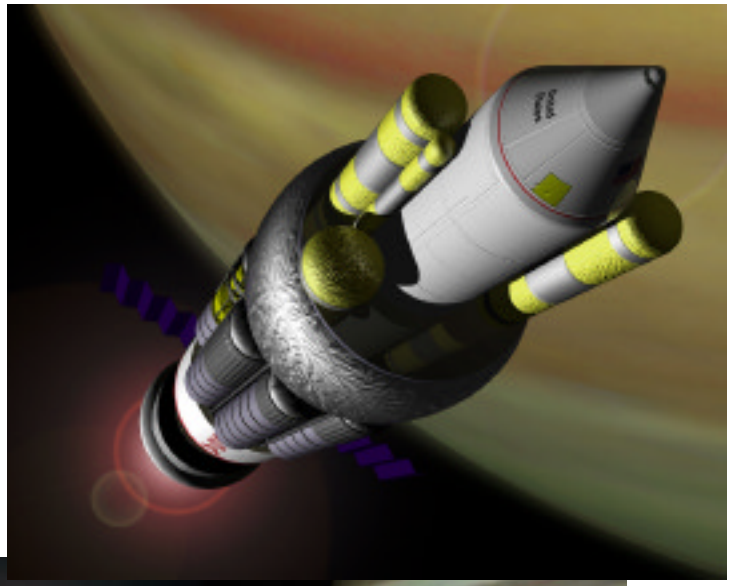
Advanced Nuclear Propulsion Concepts

- **Pluto - Nuclear Ramjet - ABCC**
  - During the “60s Livermore successfully demonstrated a proof of concept nuclear powered ramjet that traveled on a track in the Nevada Test Site. The air heat exchanger material was developed by the Coor’s brewery.
  - This project was discontinued after successfully completing all their development objectives.
  - An Atomic Based Combined Cycle concept might make an impressive vehicle for the next generation of planetary airplanes, perhaps flying through Jupiter’s atmosphere for several years.



Advanced Nuclear Propulsion Concepts Cont'd

- **Orion - A Pulsed Nuclear Concept**
  - Also during the '60s Los Alamos and others simulated a launch vehicle propulsion concept that dropped small nuclear bombs behind a blast shield. Detonation forces on the shield provided a pulsed propulsion. Large shock absorbers were required to control gravity levels, peak gee loads.
  - Isp > 10,000 seconds can be achieved.
  - May require treaty renegotiation.
  - Potential environmental issues for ETO applications.
  - Some research is being conducted by the University of Alabama in Huntsville for deep space applications utilizing components that are not and cannot be assembled into nuclear weapons.
  - The additional radiation added to the interplanetary environment probably could not be detected.
  - A concept with this performance can reduce trip times enough to enable human missions to the moons of the Jupiter or beyond.
  - A recent variation is a concept called Medusa which uses a sail to capture the nuclear blast wind.



Advanced Nuclear Propulsion Concepts

An Aneutronic Nuclear Ramjet Concept

- For this concept the nuclear fuel is Hafnium, rather than uranium or plutonium. Hafnium is a gamma ray emitter that is susceptible to stimulated emission by soft X-rays.
- The concept vehicle is envisioned to:
  - Take off using hydrocarbon fueled jet engines,
  - Start a nuclear rocket in flight to get through the pinch,
  - Transition to nuclear ramjet, and then
  - Transition to nuclear rocket when leaving the atmosphere.
  - Orbit and de-orbit maneuvers are performed with the nuclear rocket.
  - After reentry a short cruise can be sustained with the hydrocarbon engines, and aerial refueling can extend this range.
  - The vehicle lands on a runway after the reactor has cooled sufficiently.
- The reactor core is radioactive prior to launch before the nuclear engines have been turned on and therefore must be shielded.
- This radiation is gamma rays, which do not cause the vehicle structure to become radioactive like neutrons would.
- The hydrocarbon fuel can contribute to the shielding. The crew compartments, and perhaps the cargo, could be immersed in the fuel tanks
- The residual nuclear fuel can be removed and “burned” in an X-ray chamber to decontaminate it if it is impractical to recycle it.
- In the event of a catastrophe such that the nuclear fuel is dispersed there is a problem since the half-life is 31 years.
- Other alternate nuclear reactions may be possible.